'Investigation of Human Quadriceps Variation on Resting Muscle Stiffness and Brain Activation During Contraction

Paul Kennedy[1], Scott Semple[1], Calum Gray[1], Annette Cooper[1], Eric Barnhill[1], David Donaldson[2], Edwin van Beek[1], Pete Hoskins[3], Dieter Klatt[4], Ingolf Sack[4], Jürgen Braun[4], Carolyn Greig[3], Angus Hunter[5], and Neil Roberts[1]

[1]Clinical Research Imaging Centre, University of Edinburgh, Edinburgh, United Kingdom, [2]Department of Psychology, University of Stirling, Stirling, United Kingdom, [3]University of Edinburgh, [4]Charité University, Berlin, Germany, [5]Department of Sports Science, University of Stirling, Stirling, United Kingdom

Introduction

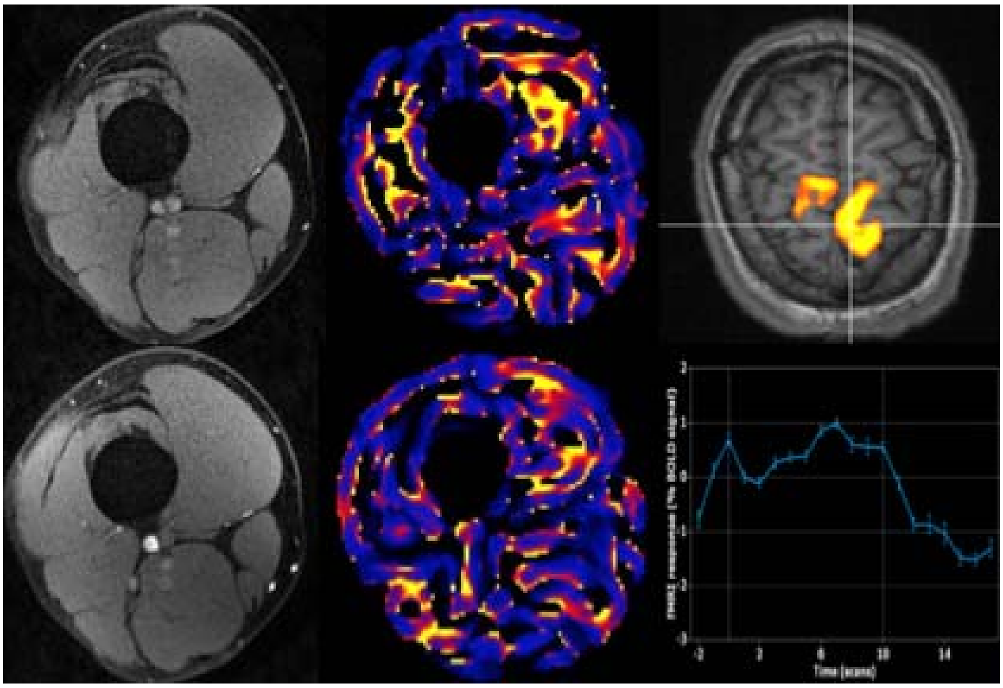
Abnormal lower-limb muscle activation is a key determinant of the characteristic pattern of stance and gait in patients following stroke but the underlying mechanisms are poorly understood and it is difficult to appropriately tailor individual exercise therapies [1]. In order to make progress information is required regarding both muscle and brain function and this can be provided by Magnetic Resonance Imaging (MRI) techniques. In particular, Magnetic Resonance Elastography (MRE) can be used to study the contraction of the relevant deep muscles [2] and functional Magnetic Resonance Imaging (fMRI) can be used to study corresponding brain function [3]. Accordingly, the potential exists to determine whether rehabilitation techniques have led to true neurological recovery or if compensatory strategies have been developed, most likely involving the unaffected side. In order to establish a clinical imaging protocol to support the development of optimum exercise therapies we have performed MRE and fMRI in healthy control subjects. This has enabled us to investigate the relationship between resting muscle stiffness and (i) normal anatomical variation in the fat fraction and amount of overlap and fusion between the muscle bellies of vastus lateralis and vastus intermedius in the human quadriceps [4] and (ii) brain activation patterns during muscle contraction.

Methods

The right quadriceps of 15 healthy male volunteer subjects were studied using a 3 tesla MRI scanner (MAGNETOM Trio, Siemens AG, Erlangen, Germany). A single axial slice was acquired during relaxation and contraction using a T1 weighted 2D FLASH sequence. MRE was performed using a modified FLASH sequence sensitized to motion by a single cycle sinusoidal MEG oscillating at 50 Hz with amplitude 30mT m^{-1} and aligned perpendicular to the image plane. Mechanical excitation was supplied to the muscle via a ring shaped actuator which was affixed to the vibration source via a carbon fibre piston. At every TR 7 cycles of a 50 Hz sinusoidal wave were applied. 8 phase offsets were acquired with a time delay of 2.5 ms per offset. 2 MRE scans were performed, one with the thigh muscle contracted and one in relaxation. A 2 block paradigm was also designed in which the subject contracted his thigh muscles to raise the leg slightly above the scanner table for a period of 30s followed by 30 s of rest. Each block was repeated 15 times resulting in a scan time of 15 minutes. fMRI data was obtained using an EPI sequence (TR/TE/Flip Angle = 3000ms/30ms/90°, slice thickness = 3mm, 20 slices, FOV = 24cm, 64 × 64 matrix size, 300 volumes). Fat infiltration was studied using a triple-echo Dixon technique and muscle morphology was examined using a T1 weighted VIBE sequence.

Results

Results for a 25 year old healthy male subject are presented in Figure 1 below. The upper and lower left panels show the anatomical images acquired of the quadriceps muscle during contraction and at rest, respectively, and the corresponding elastograms are shown in the upper and lower middle panels, respectively. Increased stiffness of the vastus medialis and vastus lateralis during contraction is clearly seen during contraction. The fat fraction of the quadriceps is 5% and the extent of overlap between vastus medialis and vastus lateralis is 23%.



The upper right panel shows the fMRI activation of left hemisphere motor cortex during contraction of the right quadriceps and the time course of the BOLD signal over the period of the contraction is shown in the lower right panel. ROI analysis of the MRE data confirmed that the stiffness of the muscles increased during contraction, with the storage modulus increasing by 46% for vastus medialis and by 10% for vastus lateralis.

Discussion and Conclusion

We have demonstrated that it is possible to use MRE to measure the effect of variations in anatomy and fat composition on the stiffness of the individual muscles of the thigh at rest and during contraction in a cohort of healthy male subjects. In addition fMRI has been used to study the brain activation patterns corresponding to the contraction of these muscles. In future studies we will apply these techniques to study the effect of exercise programmes on the recovery of motor function following stroke

References

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